"Solar Prominence and Spot Circulation, 1872—1901." By Sir Norman Lockyer, K.C.B., F.R.S., and William J. S. Lockyer, Chief Assistant, Solar Physics Observatory, M.A. (Camb.), Ph.D. (Gött.), F.R.A.S. Received March 17,—Read March 26, 1903.

[Plates 6 and 7.]

In our former communications* referring to the connection between solar, meteorological, and magnetic changes, some of the results obtained by the reduction of the solar prominences, as observed by Professor Tacchini at Rome, were described. It was stated that the curve representing the variation of percentage frequency of the prominences for the whole limb of the sun indicated that in addition to the main epochs of maxima and minima coinciding in time generally with those of the maxima and minima of the total spotted area, there were also prominent subsidiary maxima and minima.

Further, dividing the sun's limb into zones of 20° in width from the equator, with a polar zone of 10°, and discussing each zone separately, the variation of the prominence percentage frequency about the equator was found to be very different from that in the higher latitudes, the former changing with the spots, and the latter exhibiting sudden outbursts just previous to the epochs of sunspot maxima, followed and preceded by comparatively long intervals of quietude.

In the present communication, the prominence observations have been discussed from a different point of view, in order to trace out, if possible, the heliographic latitudes of the chief centres of action of prominence disturbance. In this way it could be determined whether such movements are subject to some periodic law, in which case it would be possible to increase our knowledge of the circulation of the solar atmosphere in regions outside those in which sunspots alone have, up to the present, been employed.

The changes of latitude of the zones which contain the centres of sunspot disturbances were first pointed out by Carrington,† whose fine series of observations led him to discover "a greater contraction of the limiting parallels between which spots were formed for the two years previous to the minimum of 1856, and soon after this epoch the apparent commencement of two fresh belts of spots in higher latitudes north and south, which have in subsequent years shown a tendency to coalesce, and ultimately to contract as before to extinction."

The study of the subject was taken up later by Spoerer,‡ who

* 'Roy. Soc. Proc.,' vol. 70, p. 502; vol. 71, pp. 134 and 244.

† 'Observations of the Spots on the Sun from November 9, 1853, to March 24, 1861, made at Redhill,' p. 17.

‡ 'Beobachtungen der Sonnenflecken von Oct., 1871—Dec., 1873, und von Jan.,

corroborated Carrington's results and extended the discussion of the observations up to the end of the year 1879.

The result of these two investigations showed that at sunspot maximum there was only one zone in each hemisphere in which spots were situated, the centre of this being about 18° N and S, while at minimum there were two zones existing simultaneously in each hemisphere; the older cycle dying out in the zone, the centre of which was situated in low latitudes, and the new one commencing in high latitudes, its centre being about latitude ± 30° to ± 35°.

Later observations extending up the present year have further corroborated these general deductions, for each hemisphere, and we are now quite familiar with this cycle of sunspot latitude variation.

In the present investigation, the fact has been brought out that the prominences also undergo an apparently regular variation of latitude throughout a period of about eleven years concurrently with the spots.

For the purpose of our inquiry, the object of which has been stated above, we have discussed independently of each other, two fine series of prominence observations, one made by Tacchini at Rome extending from 1872 to 1900, and the other by Ricco and Mascari at Catania from 1881 to 1901.

Both these series were handled in the same way, and both indicated similar changes of latitude of prominence action, showing that the variations recorded were real and not due to any personality of the observer or difference in the method of observation.

The data for the discussion of the solar prominences as observed by Tacchini have been taken from the same source as before,* while those of Ricco and Mascari are published in and have been extracted from the same volumes.

We may here take the opportunity to express our thanks to Professor Ricco, with whom we have been in communication, and who has very kindly forwarded for our use some unpublished data concerning his prominence observations and reductions.

The method of reduction adopted was to determine for each year the percentage frequency of prominence activity for every 10 degrees of solar latitude north and south. A series of curves was next drawn, one for each year, the abscissæ representing the latitudes of prominences north and south, and the ordinates their percentage frequency. It was then found that the centres of prominence activity, or, in other words, the maxima of the curves, were sometimes single, sometimes double, and in one or two cases even triple in each hemisphere. This suggested that just as sometimes there are two

1874—Dec., 1879.' 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' Band I and II.

* 'Società Spettroscopisti Italiani,' vol. 1, 1872, to vol. 29, 1900.

zones of spots existing at one time, so there might be one, two, or occasionally three zones of prominences in existence in each hemisphere simultaneously.

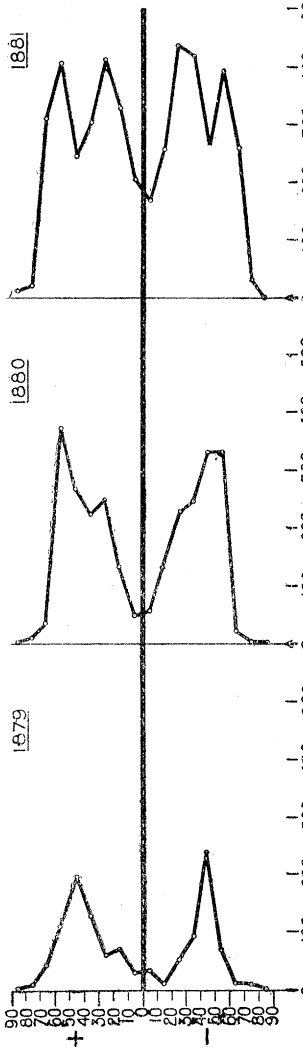

FIG. 1.—Curves showing the variation of the percentage frequency of prominence activity for every 10° of latitude for the years 1879—1881, from Tacchini's observations.

Further, a close examination of the whole set of curves with reference to these points of maxima made it possible not only to study the changes of latitude of these points from year to year and their positions when commencing to develop or about to disappear, but the intensity of these centres in relation to each other.

The accompanying illustration (fig. 1) shows the curves drawn for the years 1879, 1880, and 1881, from the observations of Tacchini, and serves as an example of the curves that have been discussed; they exhibit the change from a single to a double centre of activity in each hemisphere.

Thus in 1879, there was a prominence maximum in each hemisphere at latitudes $\pm 50°$. In the next year (1880), both the maxima had retreated further away from the equator, namely to latitudes $\pm 60°$, while another centre of disturbance began to make itself apparent at latitudes $\pm 30°$. In the year 1881, both centres in each hemisphere were strongly marked and became of about the same intensity, their mean latitudes in each hemisphere being about $\pm 30°$ and $\pm 60°$. These curves thus indicate that during these three years, the direction of motion of these centres of activity tends polewards or away from the equator.

By examining both series of observations made by Tacchini and Ricco and Mascari, and analysing the positions of the principal and

subsidiary maxima for the whole period covered by the observations, the results illustrated graphically in Plates 6 and 7 were obtained.

In these figures the facts are brought together for each hemisphere separately. The medials of the lines (curves A and B) show the heliographic latitudes of the centres of prominence action; the thickness of these lines represents the relative percentage frequency of prominence action.

For the sake of comparison, three other curves for each hemisphere are given. The first (curve C) shows the mean heliographic latitude of spotted area for each hemisphere. For the construction of these, the values, since 1873, have been extracted from the Greenwich Reductions,* but previous to that date the values have been obtained from Mr. Marth's reductions,† and those completed at the Solar Physics Observatory from measures supplied by Professor Backlund, of the Wilna Observatory.

The next curve (curve D) illustrates the variations of the percentage frequency of prominence action for each hemisphere taken, as a whole, and is similar to those given in our former papers.

The last curve (curve E) shows the variation of the mean daily area of sunspots from year to year, also for each hemisphere.

Referring now to the changes of latitude of the prominence centres of activity, both series of curves for the north as well as for the south hemisphere exhibit the same general features.

The first conclusion illustrated by the curves is that prominence activity in the main has a poleward drift, that is, the change of position of the zones of activity is in the direction from low to high latitudes. In some years, the centres of activity appear to form two zones in each hemisphere at about latitudes $\pm$ 24° and $\pm$ 50°, which eventually amalgamate at about latitude $\pm$ 40° and move polewards, fading out in about $\pm$ 70° to $\pm$ 80°. As this zone disappears in high latitudes a new zone at about latitude $\pm$ 20° begins, and this after a few years becomes associated with another zone in about latitude $\pm$ 50°, and eventually amalgamates with it.

The epochs at which these different zones come into play in relation to the general curve of prominence activity for the whole hemisphere are as follows: From a little after the maximum of prominence activity to just before the minimum, two zones in the latitudes $\pm$ 24° and $\pm$ 50° are in existence and of decreasing intensity. Before the minimum is reached these two zones amalgamate in about latitude $\pm$ 40°. At the minimum there is only one zone, and this of small intensity. Between the minimum and the following maximum this zone rapidly takes a northern movement, increasing in intensity; a new outburst

* 'Spectroscopic and Photographic Observations made at Royal Observatory, Greenwich, 1884,' and after.

† MSS. at Royal Society.

occurs in a zone nearer the equator (latitude ± 24°), which also increases rapidly in intensity.

After these general statements, we now refer to some details showing that there are some variations from the above generalisation.

For these details the curves deduced from both sets of observations made by the different observers are so very similar that it does not matter which are examined.

Attention may first be drawn to certain differences between the curves representing the latitude variation for the two hemispheres. It will be noticed that for the period 1872—1882, the curves for both hemispheres are very similar. We next consider the period 1880—1893. Here there are differences between the two hemispheres. The curve for the northern hemisphere resembles very closely that for the preceding period, but it differs somewhat from its corresponding curve for the southern hemisphere. The corresponding northern zone in latitude 45° is missing from the southern hemisphere, while a zone of activity nearer the equator about latitude 24° is present. Further, the polar zone for the southern hemisphere continues to be prominent for two years longer than that in the opposite hemisphere.

In the succeeding curves, which extend from 1891—1901, both hemispheres are more or less similar, and both resemble in a greater degree those for the southern hemisphere for the period 1880—1893 than those for the period 1872—1882.

Although the Roman and Sicilian observations give nearly identical curves, hemisphere for hemisphere, the apparently regular cycle of change of latitude which was operative for the northern hemisphere 1872—1893, and for the southern hemisphere 1872—1882, does not seem to have been so exactly maintained in late years; more irregular still perhaps is the last cycle commencing in the year 1892. Hence, there seems reason to believe that the prominence circulation is not quite the same for each cycle, and this may in some way be due to a longer solar period such as that of about 35 years.

But it is important to state that our deductions may be partially incomplete owing to the difficulty of determining sometimes whether a new centre of action has been formed or the position of an old one changed. Further, account must be taken of the fact that the material discussed does not represent the record of the percentage frequency of prominences determined from observations made on the disc of the sun (now rendered possible by the Janssen-Hale-Deslandres method), but one obtained from observations of the phenomena occurring only at the limb of the sun. The close agreement between the observation of the different observers shows nevertheless that this latter method is of great value.

Another important series of prominence observations is that made

by Father A. Fényi, S.J., who has published* the individual observations, and the reductions of the positions and frequency of prominences observed at Haynald Observatory for the years 1884 to 1890 inclusive. He gives curves constructed somewhat after the manner adopted in the present enquiry, as illustrated above, in fig. 1. A comparison of the points of maxima from his curves with those of Tacchini and Ricco and Mascari for the period common to all three sets of observations is made in the following tables, each hemisphere being given separately. The vertical columns show, for each year, the heliographic latitudes of the points of maxima, and an asterisk (*) is placed against the one which is the more or most prominent in each hemisphere; when there are two, and they are of equal intensity, this symbol is attached to each, while in the case of only slight indications of maxima the latitude is enclosed in brackets.

Northern Hemisphere.

	1884.	1885.	1886.	1887.	1888.	1889.	1890.
Tacchini	50, 25*	45, 25*	45, 20*	35	35*, 15	40	45
Ricco and Mascari	55, 20*	55, 15*	45, 25*	30	35	45	45
Fényi	65, 45, 15*	45, 25*	45, 20*	45	40*, 20	43*, 25	45

Southern Hemisphere.

	1884.	1885.	1886.	1887.	1888.	1889.	1890.
Tacchini ..	(75), 25*, 5	25	35, 20*	45*, 25	45*, 25	45	45
Ricco and Mascari	(85), 25*, (5)	25	35	45*, 25	50*, 25*	45	50
Fényi	(75), 35*, 15*	(50), 35* 10	35*, 10*	50*, 30, 15	50*, 25	40	50*, 20

It will be seen that for these seven years, Fényi's results are in very close accordance with those deduced from the other two series of observations, thus generally endorsing those portions of the curves in Plates 6 and 7 covering this period.

It was mentioned in a previous paper† that the mean prominence curve for each hemisphere exhibited subsidiary maxima and minima. In the light of the present investigation, it is interesting to compare

* 'Publicationen des Haynald-Observatoriums, Kalocsa,' Heft VI, 1892, und VIII, 1902.

† 'Roy. Soc. Proc.,' vol. 71, p. 244.

this curve with that representing the changes of latitude of the zones of prominences. In every case, and for each hemisphere, the subsidiary maxima are coincident in time with the presence of two zones of prominences, each well-developed, while at the principal minima only one zone is in evidence.

We have already explained the fact that spots are restricted to a zone having its limits at latitudes $\pm 5^\circ$ and $\pm 35^\circ$, while prominences occur all over the sun's disc, even up to the poles, and also that spots always commence their cycle in high latitudes (about $\pm 35^\circ$) and gradually approach the equator until within 5°, when a new cycle is commenced in high latitudes. Prominences on the other hand begin in comparatively low latitudes (about $\pm 24^\circ$), and finish their cycle near the poles.

A glance at the Plates 6 and 7 brings out the interesting fact that at sunspot minima, when two zones of spots are in evidence, there is only one zone of prominences, while when only one zone of spots exists the prominences are for the most part confined to two zones.

The conclusions arrived at in the present communication may be summarised as follows:—

1. The centres of action of prominence activity undergo an apparently regular variation.

2. The direction of motion of these centres is from low to high latitudes, the reverse of that of spots, which travel from high to low latitudes.

3. At epochs of prominence minima (which are concurrent with sunspot minima) these centres of action are restricted to one zone (about latitude $\pm 44^\circ$) in each hemisphere, while those of the spots occupy two zones in each hemisphere.

4. At nearly all other times these centres are apparent in two zones, while those of the spots occupy only one in each hemisphere.

5. The subsidiary maxima exhibited by the curves representing the percentage frequency of prominence activity for each entire hemisphere, are due to the presence of two well-developed centres of prominence activity in each hemisphere.

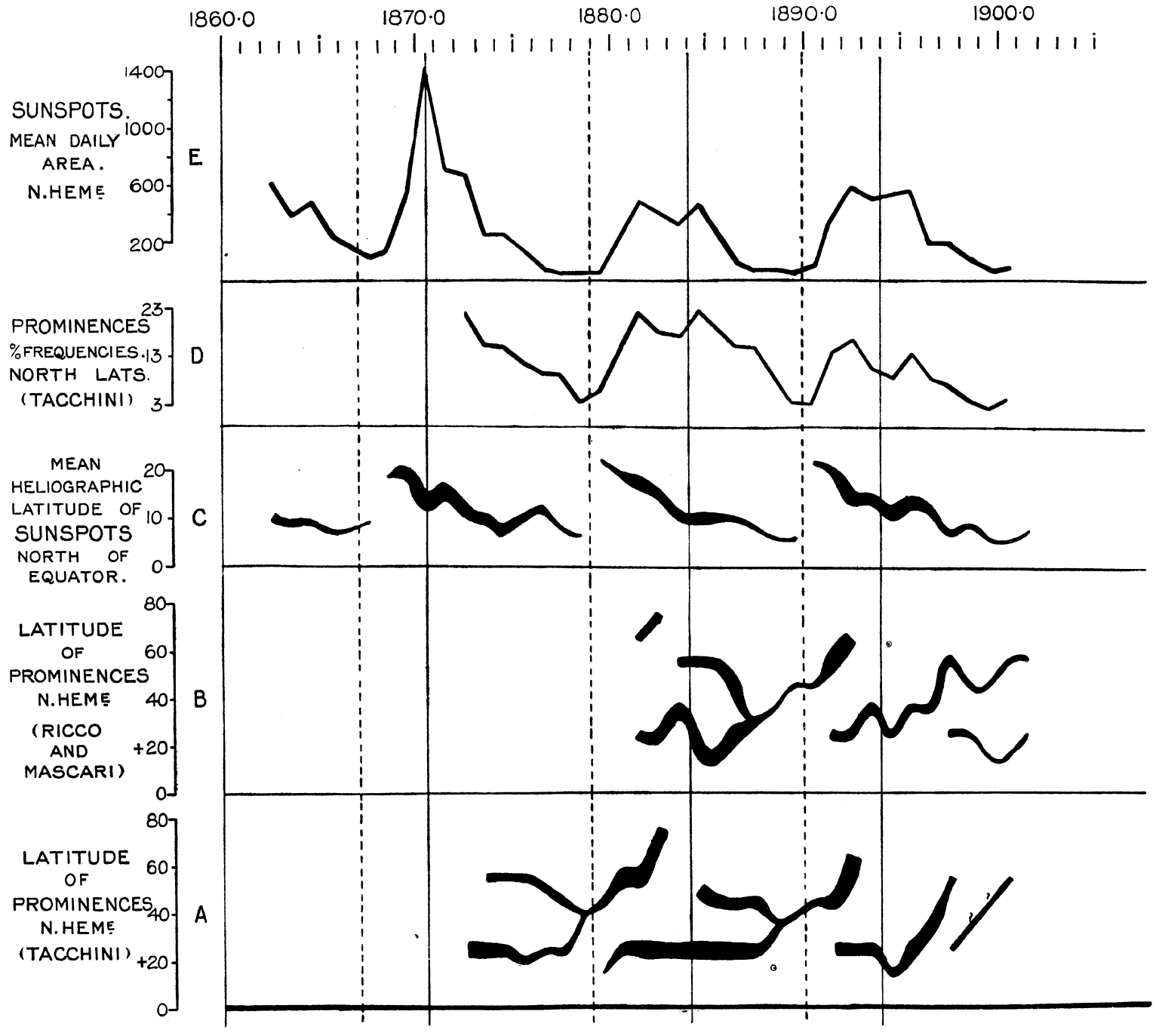

PLATE 6.—Curves showing the Relation between the Positions of the Centres of Action of Solar Prominences (A and B) and Spots (C), Percentage Frequency of Prominences (D), and Mean Daily Areas of Spots (E), for the Northern Hemisphere of the Sun.

Note.—The continuous and broken vertical lines represent the epochs of sunspot maxima and minima as determined from the mean daily areas of the whole

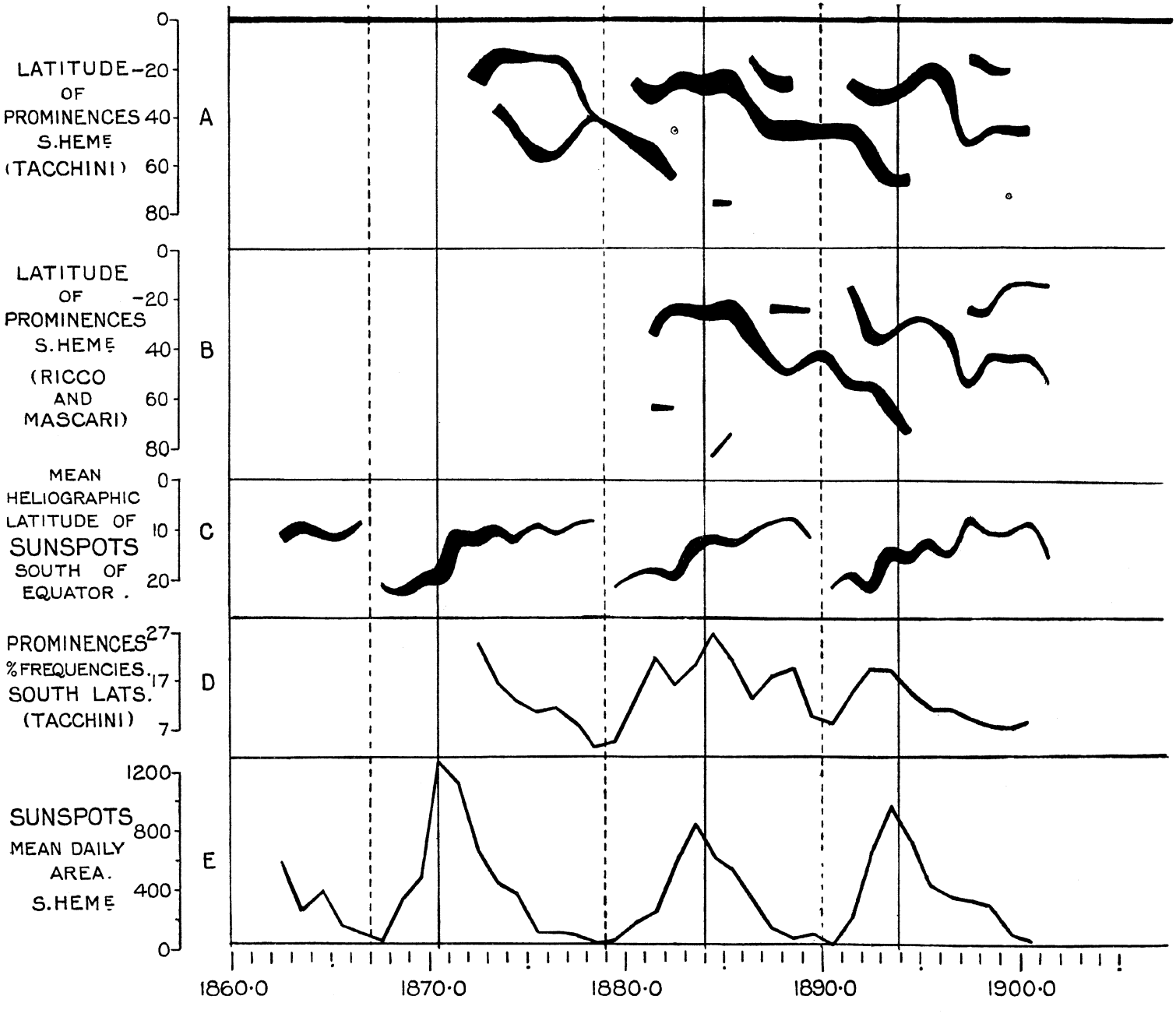

PLATE 7.—Similar Curves to those on Plate 1, only in this case the Southern Hemisphere of the Sun is referred to. Vertical lines same as on Plate 1.